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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
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Photolinker macromolecule, same attached to a metallic substrate, and optionally
covalently bonded to a ligand, and process of preparation thereof

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PHOTOLINKER MACROMOLECULE, SAME ATTACHED TO A METALLIC SUBSTRATE, AND OPTIONALLY COVALENTLY BONDED TO A LIGAND, AND PROCESS OF PREPARATION THEREOF

5 The Invention relates to a new photolinker macromolecule containing sulfur groups apt to attach to a metallic substrate by chemisorption or sulfur-metal complex formation, that photolinker macromolecule attached to a metallic substrate, and optionally covalently bonded to a ligand, generally a biomolecule, in particular for use in Surface Plasmon Resonance biosensors, 10 as well as a process for preparing same.

US Pat. Nos. 5,242,828; 5,436,161 and Lofas and Johnsson, 1990, J. Chem. Soc. Chem. Commun. 1526-28, disclose the chemical modification of metallic surfaces, such as gold surfaces, with the view to preparing sensing surfaces capable of selective molecular interactions for use in Surface 15 Plasmon Resonance (SPR) biosensor systems. Those documents describe matrix coatings on metallic surfaces, in particular gold surfaces, suitable for use in biosensors. Free electron metal surface coating is achieved by attaching a densely packed monolayer of organic molecules having hydrocarbon chains, optionally interrupted by heteroatoms, of a length 20 exceeding ten atoms with functions allowing the interaction with the free electron metal surface on one side, for instance asymmetrical or symmetrical disulfides, and an active group on the other side for covalently binding a biocompatible porous matrix via which a desired ligand can be bound. The 25 matrix is a swellable organic polymer or a polysaccharide, for instance a carboxymethyldextran.

30 The sensing surfaces thus prepared have proved useful in biosensors using SPR on gold surfaces to monitor the molecular interaction between one binding-partner, referred to as the ligand or the probe, and the other binding-partner referred to as the analyte, without any labeling. However they have the following drawbacks:

- there is an intermediate hydrophobic layer (the monolayer of organic molecules) between the ligand and the metal, which may lead to unspecific binding of the analyte to the ligand.

5 - due to the superposition of two layers, viz. a hydrophobic monolayer covalently attached to a polymer matrix, there is a large distance of the ligand to the metallic surface, and therefore of the zone of molecular interaction between the ligand and the analyte to the metallic surface. This lowers the sensitivity (the evanescent field decreases exponentially with the distance to the metallic surface).

The problem addressed by the invention is to find means and methods for preparing biosensing surfaces, in particular for use in SPR biosensors, which do not have the above drawbacks.

10 EP 0484 472 describes the chemical modification of non-metallic surfaces to achieve desired chemical and physical surface characteristics and covalent binding of biomolecules thereto. Latent reactive groups are used to achieve covalent coupling of reagents such as biomolecules with derivatized biopolymers or synthetic polymers to various non-metallic substrates. The preferred latent reactive group is typically described as a 15 photochemically reactive functional group, i.e. a photoactivatable group. When exposed to an appropriate energy source, a photoactivatable group undergoes a transition from an inactive state to a reactive intermediate capable of forming covalent bonds with appropriate materials or molecules (see e.g. 20 Sigrist et al., 1995, Optical Engineering, Vol 34, No. 8, 2339-2347). Such linking agents, for example polysaccharide-based photolinker polymers that are substituted with photoreactive groups (see Caelen et al., 2002, Langmuir, Vol 18, 2463-2467.), can be used for attaching non-reactive compounds to inert surfaces.

25 The above problem is solved by the invention as defined in the appended claims.

Indeed, the invention provides a photolinker macromolecule and a 30 method for preparing therewith sensing surfaces wherein there is no hydrophobic barrier between the ligand and the metallic surface and the distance of the ligand to the metallic surface is smaller than in the prior art, thus allowing ~~more~~ more sensitivity in SPR biosensors.

nanoassemblies and microparticles useful in the bioanalytics field, or the pharmaceutical, cosmetic or textile industry.

The invention concerns a new photolinker macromolecule, which comprises photoactivable groups and sulfur-containing groups.

5 The term "photolinker" here means, as usual in the art (see e.g. Sigrist et al., 1995 and Caelen et al., 2002, references cited above), that the macromolecule is capable of linking a substrate to a ligand using a photoreaction.

10 The photolinker macromolecule of the invention has the interesting property, new compared to known photolinker polymers, of being apt to attach to a metallic substrate by chemisorption or sulfur-metal complex formation.

15 An appropriate photolinker macromolecule is a macromolecule having a molecular weight of at least 1000 dalton, preferably at least 5000 dalton, and not possessing extensive hydrophobic domains, which comprises polymeric units and/or a sequence of similar chemical entities such as peptides or nucleic acids, some of which carry photoactivable groups and/or sulfur-containing groups.

20 The photolinker macromolecule is suitably a protein-based or polypeptide-based macromolecule, which contains photoactivable groups and thiol or disulfide groups. That macromolecule is generally derivatized from a protein or polypeptide by multiple substitutions with photoactivable groups and optionally sulfur-containing groups.

25 Such a macromolecule may be derived from a protein or polypeptide, which contains thiol or disulfide groups with metal affinity as part of its composition. Thiol and disulfide groups in proteins are present in the form of the amino acids cysteine (with a free thiol), cystine (with disulfide thiols) and methionine. Proteins or polypeptides serving as primary products for the production of protein-based or polypeptide-based photolinker 30 macromolecules may be of natural origin, synthetically produced or biosynthetically prepared following genetic engineering processes. If thiol or disulfide groups are not present in a polypeptide or as part of the natural

composition of a protein, they can be introduced by methods well known in the art (see e.g. "Bioconjugate Techniques", ed. G.T. Hermanson 1996, Academic Press). Preferably they are introduced by covalent attachment via amide bonds, by the formation of the respective thiourea derivatives, by linking of imidoesters or by substituent attachment to amino groups by Schiff base formation. Bifunctional reagents that will provide sulfur features (thiols or disulfides) as well as the specific reaction conditions with amino groups or carboxyl functions are extensively described in "Bioconjugate Techniques" (reference cited above). Interesting thiol or disulfide groups containing substitution reagents are commercial heterobifunctional or homobifunctional low molecular weight crosslinking reagents such as (N-succinimidyl 3-(2-pyridyldithio)propionate, Sulfosuccinimidyl 6-(3'-(2-pyridyldithio)-propionamido) hexanoate, sulfosuccinimidyl-6 (alpha-methyl-alpha-(2-pyridyldithio)toluamido) hexanoate, N-succinimidyl S-acetylthiopropionate, 3-((2-aminoethyl)dithio)propionic acid, dithiobis(succinimidyl propionate), dimethyl3,3'dithiobispropionimidate (all products of Pierce, Perbio Science).

For introduction of the photoreactive groups, protein-based or polypeptide-based macromolecules generally use amino terminated amino acids such as lysine providing side chain epsilon amino functions, or amino acids such as glutamic acid or aspartic acid providing side chain gamma or delta carboxyl functions, those amino or carboxylic acid being available for modification. The side chain functional groups can be reacted with amino reactive bifunctional photoactive reagents such as arylisothiocyanates or photoactive reagents with activated carboxyl functions. Examples of interesting such reagents are 4-(p-azidosalicylamido)butylamine, N-hydroxysuccinimidyl-4-azidosalicylic acid, p-azidophenyl-isothiocyanate, benzophenone-4-isothiocyanate, benzophenone-4-maleimide and 4-benzylbenzoic acid succimidyl ester. Further commercial products are listed in the catalogues of Molecular Probes, Fluka, Pierce and other suppliers of chemicals. Introduction of the photoactive functions may also be attained by formation of amide linkages between amino acid side chain carboxyl groups (aspartic acid and glutamic acid) and bifunctional photoactive reagents bearing amino functions. The latter can be covalently linked to the protein ~~bearing~~ ~~it~~ ~~can~~ ~~be~~ ~~linked~~ ~~to~~ ~~the~~ ~~protein~~ ~~bearing~~ ~~it~~ ~~can~~ ~~be~~ ~~linked~~ ~~to~~ ~~the~~ ~~protein~~

databases for proteins of natural origin. The properties mentioned can be designed for synthetic polypeptide products and for genetically engineered proteins.

5 The photolinker macromolecule is preferably a polysaccharide-based polymer, which contains photoactivable groups and sulfur-containing groups. That polymer is generally derivatized from a polysaccharide by multiple substitutions with photoactivable groups and sulfur-containing groups.

10 The polysaccharide is suitably a linear or branched polysaccharide or an artificial polymer with polysaccharide substitutions, which has a molecular weight from 1000 to 5'000'000 dalton, preferably from 5'000 to 200'000 dalton, in particular from 10'000 to 70'000 dalton.

15 The polysaccharide may be for example a polysaccharide such as agarose, dextran, carrageenan, alginic acid, starch, and cellulose, or derivatives of these such as, e.g. carboxymethyl derivatives or amino derivatives.

Polysaccharides of the dextran type, which are non-crystalline in character, in contrast to e.g. cellulose or agarose, are very suitable in those contexts. A preferred polysaccharide is thus dextran, in particular amino-dextran or carboxymethyl-dextran.

20 Following oxidative ring opening of polymer constituting monosaccharides at vicinal hydroxyl functions and introduction of amino groups at generated aldehydes the latter chemical functions become available for functionalization. The degree of substitution with sulfur-containing functional groups and photoactive groups depends on the extent 25 of the primary oxidative cleavage of polysaccharide forming monosaccharides.

There are thus several ways of adjusting the final extent of total functional groups (sulfur-containing groups and photoactivable groups) in the polysaccharide-based polymer.

30 In one preferred procedure, the final degree of total substitution is set by the primary oxidative ring opening and the substitution with sulfur-

containing groups and photoactivable groups is realized at a deliberate chosen ratio.

5 Alternatively, a variable degree of substitution is set by mixing a polysaccharide-based polymer with a high degree of substitution with a polysaccharide-based polymer having a low degree of substitution.

10 In another embodiment, the degree of substitution with the sulfur-containing groups and the photoactive groups are varied by varying the reaction conditions (e.g. reagent concentration, incubation time, or temperature) of the polymer functionalization reaction. The total available amino functions in amino dextran or carboxy functions in carboxymethyl dextran can vary between 0.005 to 1 mol per mol glucose monomer, a preferred range for subsequent functionalization with both the photoactive reagent and the sulfur-containing groups being 0.01 to 0.5 mol per mol glucose monomer.

15 The sulfur-containing groups are groups capable of chemisorption to a metal. Such groups have been described for modification of gold surfaces by, for example, Nuzzo R.G. et al., 1983, Porter M. D. et al., 1987, and Troughton E.B. et al., 1988. Suitable sulfur-containing groups are e.g. thiol (-SH), thioacid (-COSH), dithioacid (-CSSH), sulfide (-S-) and disulfide (-SS-).

20 Reagents for introducing sulfur-containing groups into the polysaccharide-based polymer are (N-succinimidyl 3-(2-pyridyldithio)propionate, Sulfosuccinimidyl 6-(3'-(2-pyridyldithio)-propionamido) hexanoate, sulfosuccinimidyl-6 (alpha-methyl-alpha-(2-pyridyldithio)toluamido) hexanoate, N-succinimidyl S-acetylthiopropionate, 25 3-((2-aminoethyl)dithio)propionic acid, dithiobis(succinimidyl propionate), dimethyl3,3'dithiobispropionimidate and others as provided by Fluka Chemicals, Molecular Probes, Pierce and other suppliers of special chemicals.

30 The photoactivable groups are groups that upon photoactivation generate intermediates apt to undergo insertion reactions with covalent bonds of biomolecules. Suitable photoactivable groups are described in

radicals of the benzophenone moiety, and arylazides, which generate nitrenes.

Preferred photoactivable groups are aryldiazirines and benzophenones. Aryldiazirines and benzophenone based photoactive groups are photochemically activated and the photochemical intermediates are generated by irradiation with actinic light at 350 nm. Any light source is applicable presuming sufficient irradiance at the wavelength requested. A specific requirement for the photoactivation of linker polymers bound to metallic substrates is the elimination of high energy radiation by filtering all incident light below 320 nm with a cut-off filter, such as not to break the chemisorptive linkage between the metal and the sulfur-containing group. Preferred activation of sulfur-containing photolinker polymers on metal surfaces is effected, for instance, by irradiation for 4 min with, for instance an Oriel Lamp (350 nm, 11 mW/cm²). Alternative light sources that generate the same irradiance can be used instead (e.g. Stratalinker with 365 nm tubes, 1 mw/cm², 45 min irradiation).

Examples of preferred reagents for introducing photoactivable groups are 4-(p-azidosalicylamido)butylamine, N-hydroxysuccinimidyl-4-azidosalicylic acid, p-azidophenyl-isothiocyanate, benzophenone-4-isothiocyanate, benzophenone-4-maleimide, 4-benzylbenzoic acid succinimidyl ester, 3-(trifluoromethyl)-3-(m-isothiocyanophenyl) diazirine and other aryldiazirine containing reagents.

The invention also relates to the above photolinker macromolecule attached to a metallic substrate.

Suitable metals for the metallic substrate are free electron metals which show affinity for sulfur, such as e.g. copper, aluminum, cadmium, iron, manganese, silver, gold and platinum. Preferred metals are copper, aluminum, silver, gold, palladium and platinum.

The metallic substrate may widely vary in shape, e.g. plate-shaped, spheroid, cylindrical, pyramidal, or rod-like, and in size (from a few nanometers to any dimension). For use as a sensing surface in a SPR biosensor, the metallic substrate is generally plate-shaped.

The attachment to the metal occurs spontaneously at room temperature by chemisorption as described in the art for thioalkane self-assembled monolayers (see e.g. G.M. Whitesides, 1996, Ann. Rev. Biophys. Biomol. Struct., 25, 55-78) or by sulfur-metal complex formation processes.

5 Incubation at elevated temperatures, from 30 to 60 °C, completes the reaction within a short time and stabilizes the interaction.

The above photolinker macromolecule can be used for attaching a functionalized coating to a metallic substrate.

The Invention also relates to the above photolinker macromolecule attached to a metallic substrate, which is covalently bonded to a ligand.

The ligand (also called "probe") can be any molecule of interest depending on the application. Generally it is a biomolecule, e.g. a protein or a nucleic acid, in an active form.

Covalent binding of the ligand to the photolinker macromolecule attached to a metallic substrate is preferably effected by submitting a mixture of those two components to a photoreaction. The photoactivatable groups generate highly reactive species such as carbenes or nitrenes with very short half times, which react with neighboring ligand molecules, forming covalent bonds. When the ligand is a biologically active biomolecule, the above photoreaction allows to retain its activity.

Covalent binding of the ligand to the photolinker macromolecule attached to a metallic substrate may also be effected thermally at elevated temperature.

The above photolinker macromolecule attached to a metallic substrate and covalently bonded to a ligand can be used as part of a biosensing surface of a biosensor system, particularly a SPR biosensor. Such a biosensor has an enhanced sensitivity thanks to the short distance between the ligand and the metallic surface. It can be used for all kinds of analytes, even those partially hydrophobic or low molecular weight, thanks to the absence of a hydrophobic barrier between the ligand and the metallic

— 1 —

That photolinker macromolecule attached to a metallic substrate and covalently bonded to a ligand is also very useful as part of a microarray where a large number of different immobilized biomolecules such as proteins or nucleic acids are displayed.

5 That photolinker macromolecule attached to a metallic substrate and covalently bonded to a ligand may also be used for preparing, i.e. functionalizing, nanoparticles, nanoassemblies or microparticles. The latter may carry as ligand a biologically active substance, e.g. an antibacterial or a 10 cosmetically or pharmaceutically active substance. Such particles or assemblies can be used in the cosmetic industry or the healthcare industry, e.g. as means of administration of active substances, or in the textile industry, e.g. for immobilizing antibacterials on textile fibers.

Nano- or microparticles thus prepared are also of interest in the bioanalytics field.

15 The invention will be further described by the following examples which have an illustrative but not limitative character.

The description below will be better understood by referring to Figures 1, 2A, 2B, 2C, 2D, 3 and 4.

20 Figure 1 is a reaction scheme showing derivatization of Optodex A into Optodex S and Optodex SH.

Figure 2A is a photograph of a mask used for photopatterning comprising a lattice-shaped pattern of transparent (white) zones and light-absorbing (dark) zones.

25 Figure 2B is a fluorescence scanograph of an Optodex S treated gold plated platform to which Cy5-labeled riboflavin binding protein (RBP) has been added, after ultraviolet irradiation using the photomask of Figure 2A.

30 Figure 2C is a fluorescence scanograph of an Optodex S treated gold plated platform to which Cy3-labeled bovine serum albumin (BSA) has been added, after ultraviolet irradiation using the photomask of Figure 2A.

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Figure 2D is a fluorescence scanograph of an Optodex S treated gold plated platform to which mouse immunoglobulin (m-IgG) has been added, after ultraviolet irradiation using the photomask of Figure 2A and immunocomplexation with Cy-5 labeled goat anti-mouse IgG antibody.

5 Figure 3 is a fluorescence scanograph of 4 printed microarrays (arrays 1, 2, 3 and 4, each 20 x 20 spots, parallel printed with 4 pins) of fluorophore labeled proteins after photoimmobilization on a gold platform.

10 Figure 4 is a Surface Plasmon Resonance sensogram of vitamin B₂ binding to riboflavin binding protein (RBP) after its photoimmobilization on OptoDex S modified gold platform.

EXAMPLE 1 Synthesis and characterization of OptoDex S and OptoDex SH

a) Synthesis of Optodex S and Optodex S-H (cf. Figure 1)

15 Each of OptoDex S and OptoDex SH (reduced OptoDex S) is a photolinker polymer which is a multiply substituted aminodextran functionalized with both photoactive and sulfur (thiol and/or disulfide) containing substituents. The synthesis of those photolinker polymers is illustrated in Figure 1.

20 The starting material is photolinker polymer OptoDex A, which is obtained by partial thiocarbamoylation of aminodextran with photolinking reagent 3-(trifluoromethyl)-3-(m-isothiocyanophenyl) diazirine (see I. Caelen, H. Gao and H. Sigrist, Langmuir, Vol 18, 2463-2467). That photolinker polymer is derivatized on the residual amino functions with the reagent sulfosuccinimidyl-6-[3'-(2-pyrimidylthio)-propionamido] hexaoate (LC sulfo 25 SPDP). The reaction product is photolinker polymer OptoDex S carrying an activated disulfide group. Treatment of OptoDex S with the reducing agent dithiothreitol yields a reduced form thereof carrying free thiol functions, photolinker polymer OptoDex SH.

OptoDex S is prepared according to the following detailed procedure.

1. Dissolve 100 mg OptoDex A in 10 ml DMF.

2. Add 100 mg 3-(trifluoromethyl)-3-(m-isothiocyanophenyl) diazirine.

3. Add 100 mg LC sulfo SPDP.

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isothiocyanophenyl) diazirine by reaction of aminodextran at 2.0 mg/ml and the diazirine aryl isothiocyanate at 0.3 mg/ml in 0.1 M sodium carbonate buffer, pH 9.0 for 5 hours at 37°C. Upon completion of the reaction, excess photoreagent is removed by exclusion chromatography on Sephadex G 25 in 5 diluted aqueous buffer (1:100 diluted phosphate buffered saline). Fractions eluting in the void volume contain the substituted aminodextran product: OptoDex A, functionalized with the above photoreactive reagent. Pooled fractions are lyophilized and stored at -18°C, as required. For further functionalization, OptoDex A containing approximately 14 mol amino groups per mol OptoDex A, is dissolved in phosphate buffered saline (PBS), pH 7.4 10 at a concentration of 2.0 mg/ml. To this solution, 100 µl of a freshly prepared solution of LC-Sulfo-SPDP (5.2 mg/ml phosphate buffered saline) is added. The mixture of the two solutions is incubated at ambient temperature with continuous stirring. Upon completion of the reaction (after about 1h) the 15 reaction mixture is purified by chromatography on a PD 10 column (Pharmacia) using phosphate buffered saline containing 1 mM EDTA pH 7.4 as elution buffer. Fractions of 1 ml are collected and the absorption at 350 nm is recorded for product identification. Unless immediately used, the product, OptoDex S, is stored at -18 °C.

20 OptoDex S contains activated disulfide groups allowing facilitated disulfide exchange reactions. The reduced form of OptoDex S is obtained by treatment of OptoDex S with 5 mM dithiothreitol in 10 mM sodium acetate buffer, pH 5.0 and incubation of the reaction mixture at 37 °C for 60 minutes. The reaction product is OptoDex SH (containing free thiol groups). It is 25 purified by chromatography on Sephadex G10. Immediate use of the product is recommended as inter- and intramolecular disulfide bridge formation may spontaneously occur.

b) Characterization of OptoDex S

30 The product OptoDex S is supposed to contain photoactive aryldiazirine functions as well as activated disulfide functions. The presence of each of those chemical functions is demonstrated by the two analytical procedures outlined below. In each of those procedures, a sample of OptoDex A (photoactive, but not containing disulfides or thiols) serves as control and an additional analytical control includes samples which are not exposed to 35 activating light.

Determination of the sulfide content of OptoDex S.

The sulfide content of Optodex S is determined by reducing Optodex S to OptoDex SH as described above and determining the content of free thiols thereof using the thiol and sulfide quantitation kit T-6060, available from 5 Pierce Chemicals. OptoDex S is dissolved at a concentration of 0.2 mg/ml in deionized water and 100 μ l of the solution is pipeted into a microplate (Nunc-Immuno Module Polysorp F8). The microplate material is polystyrene and 8 replicas of each sample are prepared with OptoDex S as well as with OptoDex A serving as control. After adsorptive binding for 90 minutes at 10 ambient temperature the microplate wells are rinsed with water and dried in vacuum for 90 minutes at 5×10^{-2} mbar. Coated wells are then irradiated for 4 minutes with the Oriel light source (wavelength 350 nm, irradiance 11 mW/cm²) and subsequently rinsed with phosphate buffered saline containing 0.05% Tween (3 times), followed by phosphate buffered saline (3 times) and 15 deionized water (3 times). Control samples (- Light) are identically treated but not irradiated. For sulfide quantitation purposes, photoimmobilized OptoDex S (or OptoDex A as control) is treated with 100 μ l 5mM dithiothreitol in 10 mM sodium acetate buffer, pH 5.0, yielding Optodex SH. All samples are incubated during 60 minutes at 37 °C and then rinsed 3 times with deionized 20 water. The presence thiols generated from OptoDex SH is analyzed with the thiol and sulfide quantitation kit (colorimetric assay). The results are summarized in the table below.

Samples	Thiol groups (pmol / well)	
	+ Light activated	- Light
OptoDex S	29.8 ± 4.9	4.2 ± 2.3
OptoDex A	5.5 ± 0.40	2.3 ± 2.2

25 The above table shows that photoimmobilized OptoDex SH contains approximately 127 pmol reactive thiol SH groups (equivalent to 10 nmol 20 thiol groups) and 2.3 pmol reactive thiol SH groups (equivalent to 2.3 nmol thiol groups) in the absence of light.

Photoactivity of OptoDex S.

The photoactivity of OptoDex S is tested by light-dependent immobilization of the enzyme alkaline phosphatase onto polystyrene, using as photolinker polymer OptoDex S (or OptoDex A as control).

5 OptoDex S is mixed with alkaline phosphatase (2000-3000 DEA units per mg protein, purchased from Sigma) in a weight ratio 8:1 (w/w), and applied to micro plate wells (Nunc-Immuno Module Polysorp F8, from Nunc, Denmark). The final quantity of alkaline phosphatase added to each well is 200 ng. The volume added per well is 40 μ l, adjusted with diluted (1:100) phosphate buffered saline containing 10% ethanol (v/v). After drying for 3 hours under vacuum (1 hour at 20 mbar, 2 hours at 5×10^{-2} mbar), coated surfaces are irradiated for 4 minutes with the Oriel Lamp (wavelength 350 nm, 11 mW/mm²). The surfaces are then rinsed with PBS/Tween™ (3 times), PBS (3 times) and deionized water (3 times). Each rinsing step consists of shaking for 5 minutes. Eight replicates of each sample were tested.

10 15 The enzymatic activity of photoimmobilized alkaline phosphatase is detected using the Alkaline Phosphatase Substrate Kit from Pierce. The substrate solution is freshly prepared according to the product description and applied to wells (100 μ l/well). Microplates are incubated during 30 minutes at 37°C, and the reaction is stopped by addition of NaOH, 2.0N (50 μ l/well). Color developed is determined by measuring the absorption at 405 nm with a commercial microplate reader. The results obtained with 8 replicate samples are summarized in the table below (+ Light: exposure of the sample to activating light; -Light: no exposure to activating light).

	Surface content	Assay condition	Alk. Phosphatase activity (E 450 nm)
Sample	OptoDex S and alkaline phosphatase	+ Light	2.333
		- Light	0.058

Control 1	OptoDex A and alkaline phosphatase	+ Light	2.256
		- Light	0.064
Control 2	OptoDex S	+ Light	0.055

The above table shows that upon light activation OptoDex S, like OptoDex A, immobilizes alkaline phosphatase on polystyrene while retaining its activity.

EXAMPLE 2 Coating of gold surfaces with OptoDex S and mask-assisted study of photoimmobilization thereon of biomolecules

The gold platforms used for OptoDex S coating are silicon chips of 12 x 12 mm with a top 150 nm gold layer on a Si₃N₄ coated silicon wafer. Those chips are first rinsed 3 times with isopropanol and cleaned with oxygen plasma for 3 minutes at room temperature.

a) OptoDex S chemisorption on gold surfaces

OptoDex S coating of gold is achieved by adding to each gold coated platform 50 µl of a solution of 1.0 mg OptoDex S per ml diluted (1:100) phosphate buffered saline to the gold coated chip. To achieve homogeneous chemisorption of OptoDex S, the platforms are kept in a humid chamber for 5 hours at 37 °C. After this step, platforms are rinsed with deionized water and dried for 1 hour at 5 x 10⁻² mbar. Unless immediately processed, OptoDex S treated gold surfaces are stored vacuum packed at -18 °C.

b) Photoimmobilization of biomolecules to OptoDex S treated gold surfaces

Photoimmobilization of a biomolecule to OptoDex S treated gold surfaces is attained by diluting the biomolecule to a final concentration of 0.2 mg/ml with phosphate buffered saline (1:100). The biomolecules used in this set of experiments are fluorophore (Cy5)-labeled riboflavin binding protein, Cy3-labeled bovine serum albumin or non-labeled mouse immunoglobulin. The dilution is added to the OptoDex S treated gold surface and the mixture is incubated for 1 hour at room temperature.

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binding of the biomolecules to OptoDex S coated gold surfaces is achieved by irradiating the surfaces during 5 minutes with the Oriel light source (350 nm, irradiance 11 mW/cm², in presence of a UV cut-off filter), using a patterned photomask (see Figure 1A) for easy demonstration of the light-dependency of the immobilization reaction.

Following photoimmobilization the surface treated gold platforms are thoroughly rinsed by sequential treatment (5 minutes each) under continuous agitation with the following solutions: 1% serum albumin in phosphate buffered saline (once); phosphate buffered saline containing 0.02 % TweenTM 20 (3 times); phosphate buffered saline (3 times); deionized water (3 times).

Mouse immunoglobulin m-IgG, which carries no fluorophore is immunocomplexed with Cy-5 labeled goat anti-mouse IgG antibody. Immunostaining with Cy5 labeled goat anti-mouse immunoglobulin antibody is attained by incubation of the platform during 30 minutes at 37 °C in a solution containing a diluted antibody preparation (1:200 diluted with phosphate buffered saline containing 1% bovine serum albumin). Prior to imaging, the immunostained surfaces are rinsed (3 times each) with phosphate buffered saline containing 0.05 % Tween 20, phosphate buffered saline and deionized water

Photopatterned fluorophore-labeled proteins are imaged by scanning with a confocal array scanner. The scanner settings on the Affymetrix Array scanner 428 being set at: gain 50, focus 0.1 for both Cy5 and Cy3.

The results of fluorescence scanning are shown on the scanographs of Figures 2B, 2C and 2D.

Figure 2B is a fluorescence scanograph of an Optodex S treated gold plated platform to which Cy5-labeled riboflavin binding protein (RBP) has been added, after ultraviolet irradiation using the photomask of Figure 2A.

Figure 2C is a fluorescence scanograph of an Optodex S treated gold plated platform to which Cy3-labeled bovine serum albumin (BSA) has been added, after ultraviolet irradiation using the photomask of Figure 2A.

Figure 2D is a fluorescence scanograph of an Optodex S treated gold plated platform to which mouse immunoglobulin (m-IgG) has been added, after ultraviolet irradiation using the photomask of Figure 2A and immunocomplexation with Cy-5 labeled goat anti-mouse IgG antibody.

5 Those scanographs show that each of the 3 biomolecules is immobilized on the OptoDex treated gold surface only in the zones of irradiation (appearing as light emitting) and not the zones where irradiation has been stopped by the mask.

10 **EXAMPLE 3** Coating of gold surfaces with Optodex S and study of photoimmobilization of biomolecules using standard microarray printing technology

This example demonstrates the use of OptoDex modified gold platforms for the manufacturing of microarrays with a conventional microarrayer (Affymetrix Array Printer 417). Gold platforms used in this set of experiments 15 are commercial gold coated glass slides (75mm x 25mm x 1mm) as available for instance from Erie SA (BioGold). Gold-coated slides are treated for 3 minutes with oxygen plasma to effect cleaning of the gold surface. The gold surface is chemisorbed with OptoDex S by incubating the slide platforms during 5 hours at 37°C in an OptoDex S solution (0.5 mg OptoDex S per ml 20 diluted (1:100) phosphate buffered saline). After this treatment the slide surfaces are rinsed with deionised water and dried in a vacuum chamber during 1 hour at 5×10^{-2} mbar. Such treated surfaces can be stored at -18°C until further use.

25 For demonstration purposes, two types of biomolecules are used for array printing: Cy5-labelled mouse immunoglobulin and Cy3 labeled bovine serum albumin. 400 spot repeat arrays of each biomolecule preparation are printed with the Affymetrix Array printer 427 (pin-and-ring printer, simultaneous printing with 4 pins). Covalent binding of the spotted biomolecules to OptoDex S coated gold surfaces is achieved by irradiating the surfaces 30 during 6 minutes with the Oriel light source (350 nm, irradiance 11 mW/cm², with an UV cut-off filter). Following light exposure, the platforms are

Tween™ 20 (3 times); phosphate buffered saline (3 times); deionized water (3 times). Printed arrays are imaged by reading with the Affymetrix Array reader.

The result of such an experiment is shown in Figure 3. 400-spot microarrays 5 are printed in parallel with the 4 pins of the Affymetrix Array Printer. Array 1 is a repeat array of a solution containing Cy5-labelled mouse immunoglobulin. Array 2 represents a repeat array of a solution containing a 1:1 mixture of Cy5-labelled mouse immunoglobulin and OptoDex A. Correspondingly, array 3 is a repeat array of a solution of Cy3-labelled 10 bovine serum albumin. Array 4 shows a print of a solution containing a 1:4 mixture of Cy3 -labeled bovine serum albumin and OptoDex A.

This example shows the feasibility of using standard printing technology for making microarrays with a large number of different proteins immobilized thereon.

15 **EXAMPLE 4** Direct measurement of Vitamin B₂ binding to photoimmobilized riboflavin binding protein by Surface Plasmon Resonance on gold platforms

This sequence of experiments provides evidence that the riboflavin (i.e. 20 vitamin B₂) binding protein RPB can be photoimmobilized on gold platforms. Furthermore, the conditions for RBP binding and assay conditions are elaborated with RBP photoimmobilized on microplates. Finally, evidence is provided that the combination of photoimmobilized RBP on gold can be used for the direct quantitative measurement of vitamin B₂.

The retention of biological activity of photoimmobilized RBP has been 25 confirmed in a microplate assay system prior to elaboration of the vitamin B₂ binding assay on gold platforms. Two procedures for biomolecule immobilization have been tested: a) layer coating of RBP and b) co-immobilization of RBP, both systems use OptoDex A as linker polymer, and vitamin B₂ binding is detected by fluorescence quenching: Riboflavin (vitamin 30 B₂) fluoresces in solution. The intrinsic fluorescence is quenched when the vitamin binds to RBP. Therefore, the more vitamin B₂ binds to RBP the stronger is the quenching of the intrinsic fluorescence of vitamin B₂. Fluorescence quenching is thus indicative for the bioactivity of the

immobilized RBP. Both types of assay are carried out on polystyrene microplates. Out of the two procedures mentioned, co-immobilization yielded high vitamin B₂ binding activity and low unspecific binding. Based on the results obtained, the co-immobilization process is preferably used for probe molecule immobilization onto gold surfaces, as demonstrated with RBP.

5 Photoimmobilization of riboflavin binding protein (RBP) on gold.

The experimental procedure for riboflavin binding protein (RBP) immobilization on gold surfaces is detailed in Example 2. Identical procedures are followed, with the difference however that native (non-labeled) RBP was used instead of fluorophore-labeled RBP.

10

a) Pretreatment of gold platforms and functionalization with OptoDex S.

15 Gold platforms (Biacore Au Sensor chip) designed for the use in the Biacore QC analytical detection system are obtained from Biacore AB, Sweden. The gold surfaces are pretreated with oxygen plasma for 3 minutes at ambient temperature. OptoDex S is dissolved in phosphate buffered saline (1:100 diluted) at a final concentration of 1 mg/ml, and 50 μ l of this solution is applied to the gold platform with a pipette. Binding of OptoDex S to gold is attained by incubation at 37°C for 5 hours at 80% humidity. Treated surfaces 20 are then rinsed with deionized water and dried in a vacuum chamber during 1 hour at 5 \times 10⁻² mbar. Resulting OptoDex S modified gold platforms are vacuum-packed and stored at -18°C until further used.

20

25 b) Covalent attachment of RBP to OptoDex S modified gold platforms

30 RBP is dissolved in phosphate buffered saline (1:100 diluted) at a concentration of 0.2 mg/ml and applied to OptoDex S modified gold platforms platform (25 μ l/chip). Following layer coating procedures, RBP is mixed with OptoDex A (ratio 1:2, w/w) in diluted (1:100) phosphate buffered saline and the mixture is applied to OptoDex S modified gold platforms. The platforms are then dried in vacuum during 20 minutes at 20 mbar and 1 hour.

35

RBP, the platforms are rinsed by applying the following treatment in this sequence: a) phosphate buffered saline containing 0.02 % Tween 20, b) phosphate buffered saline, c) deionized water, each rinsing step being carried out for 5 minutes under agitation. Platforms with covalently attached RPB are vacuum-packed and stored at -18°C until further used.

5 c) Vitamin B₂ binding to RBP detected by Surface Plasmon Resonance.

Detection of vitamin B₂ binding to photoimmobilized RBP is effected with the Biacore QC instrument. Biacore Au Sensor chips are modified as described above and introduced in the Bioacore QC instrument. A solution vitamin B₂ (5 to 50 µg vitamin B₂ in water containing 0.12 % v/v acetic acid) is injected and vitamin B₂ binding is registered by recording the mass change deposited on the surface (RU = relative units). In the experiment shown in Figure 4, saturation of vitamin B₂ binding is achieved in 4 minutes. After 4 minutes the surface is rinsed with deionized water containing 0.12 % acetic acid (rinsing buffer). The interaction of vitamin B₂ with the immobilized RBP can be reversed by exposure of the surface with a regeneration buffer consisting of 0.033 % sodium dodecyl sulfate in 0.1 M phosphate buffer, pH 4.5.

10 The above shows that biomolecules immobilized on a coating of OptoDex S 15 on a gold surface retain their biological activity and therefore can act as ligands in a biosensor.

CLAIMS

1. Photolinker macromolecule comprising photoactivable groups and sulfur-containing groups.
2. Photolinker macromolecule of claim 1, which is a protein-based or a polypeptide-based macromolecule that contains photoactivable groups and thiol or disulfide groups.
3. Photolinker macromolecule of claim 1, which is a polysaccharide-based polymer.
4. Photolinker macromolecule of claim 3, wherein the polysaccharide has a molecular weight from 1000 to 5'000'000 dalton, preferably from 5'000 to 200'000 dalton, in particular from 10'000 to 70'000 dalton.
5. Photolinker macromolecule of claim 3 or 4, wherein the polysaccharide is selected from the group consisting of agarose, dextran, carrageenan, alginic acid, starch, and cellulose, and a derivative thereof.
6. Photolinker macromolecule of claim 5, wherein the polysaccharide is dextran, in particular amino-dextran or carboxymethyl-dextran.
7. Photolinker macromolecule of any of claims 3 to 6, wherein the sulfur-containing groups are selected from the group consisting of thiol (-SH), thioacid (-COSH), dithioacid (-CSSH), sulfide (-S-) and disulfide (-SS-).
8. Photolinker macromolecule of any of claims 3 to 7, wherein the photoactivable groups are selected from the group consisting of aryliazirines and benzophenones.
9. Photolinker macromolecule of any of claims 3 to 8, wherein the photoactivable groups are selected from the group consisting of 4-(2-bromo-2-oxo-3-phenylpropylidene)-1,3-dihydro-2H-1,2-diazepine-2-carboxylic acid p-

phenone-4-maleimide, 4-benzylbenzoic acid succimidyl ester, or 3-(trifluoromethyl)-3-(m-isothiocyanophenyl) diazirine

10. Photolinker macromolecule of any of claims 1 to 9, attached to a metallic substrate.

5 11. Photolinker macromolecule of claim 10, wherein the metal is selected from the group of aluminum, copper, gold, palladium, platinum and silver

12. Photolinker macromolecule of claim 10 or 11, attached to a metal substrate and covalently bonded to a ligand.

10 13. Sensing surface of biosensor, which comprises a photolinker macromolecule of claim 12.

14. Microarray, which comprises a photolinker macromolecule of claim 12.

15 15. Nanoparticle, nanoassembly or microparticle comprising a photolinker macromolecule of claim 12.

16. Process of preparing a photolinker macromolecule of any of claims 3 to 9, which comprises derivatizing a polysaccharide by multiple substitution with photoactivable groups and sulfur-containing groups.

20 17. Process of preparing a photolinker macromolecule of claim 12 which comprises submitting a mixture of a photolinker macromolecule of claim 10 with a ligand to a photoreaction.

18. Use of the photolinker macromolecule of any of claims 1 to 9 for attaching a functionalized coating to a metallic surface.

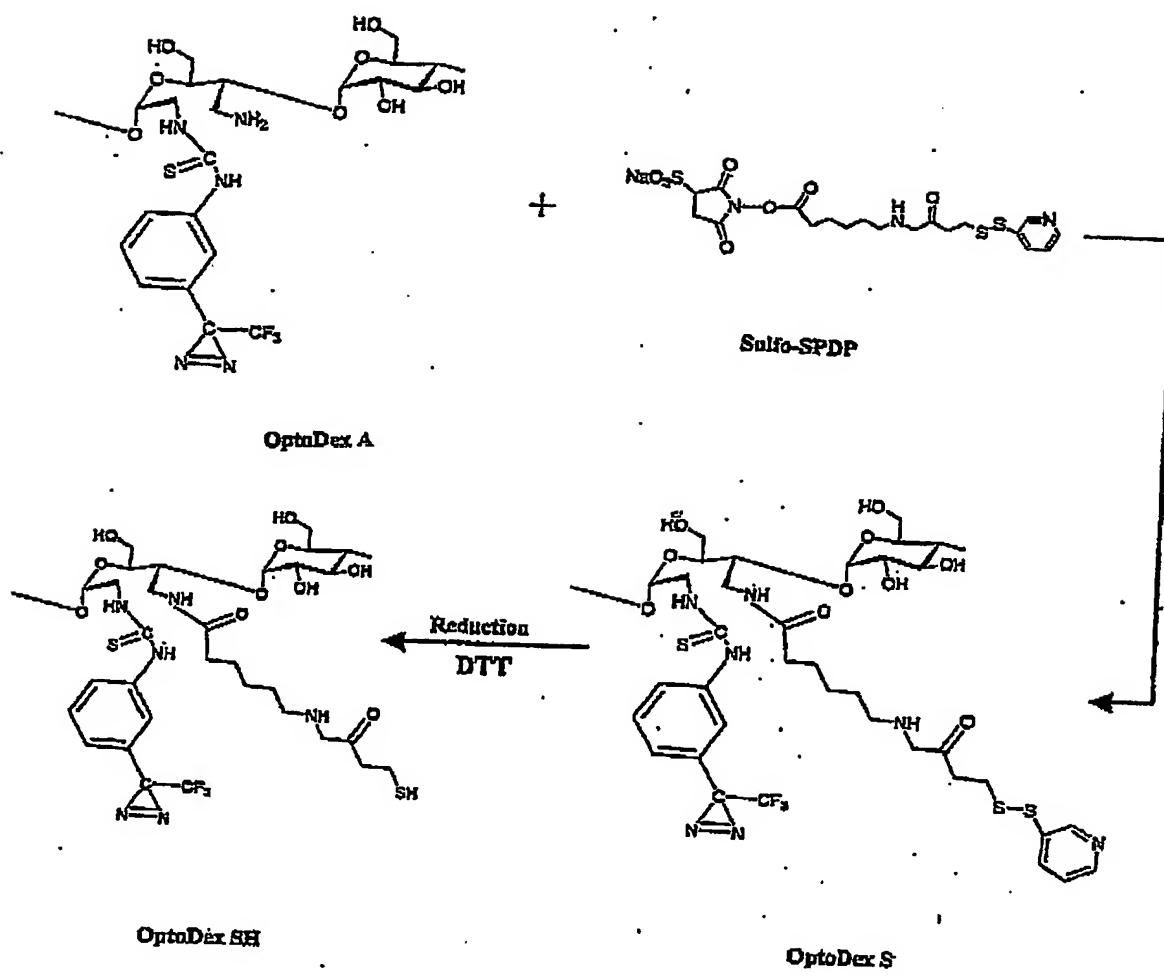
25 19. Use of the photolinker macromolecule of any of claims 1 to 12 in the pharmaceutical, cosmetic or textile industry.

ABSTRACT

The invention relates to a photolinker macromolecule comprising photoactivable groups and sulfur-containing groups, that photolinker macromolecule attached to a metallic substrate, and optionally covalently bonded to a ligand, and the use thereof in biosensor systems, microarrays, nanoparticles, nanoassemblies and microparticles useful in bioanalytics, or the pharmaceutical, cosmetic or textile industry.

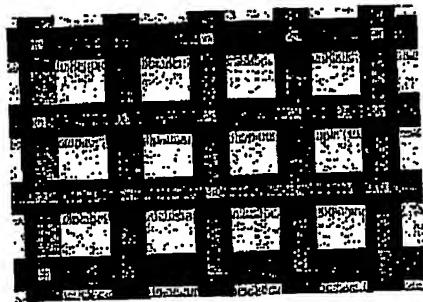
- 22 -

FIG 1.



- 23 -

FIG 2



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FIG. 2A

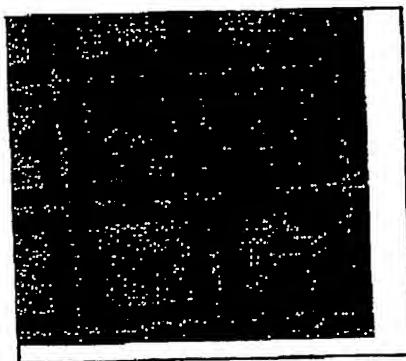


FIG. 2B

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15

20

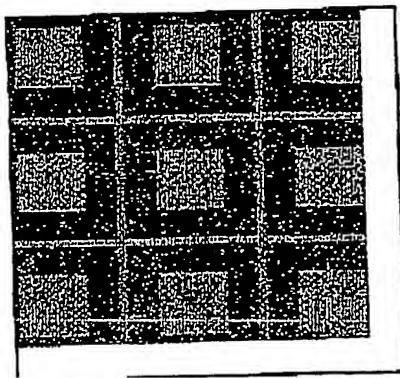


FIG. 2D

FIG. 2C

25

- 24 -

FIG 3

5

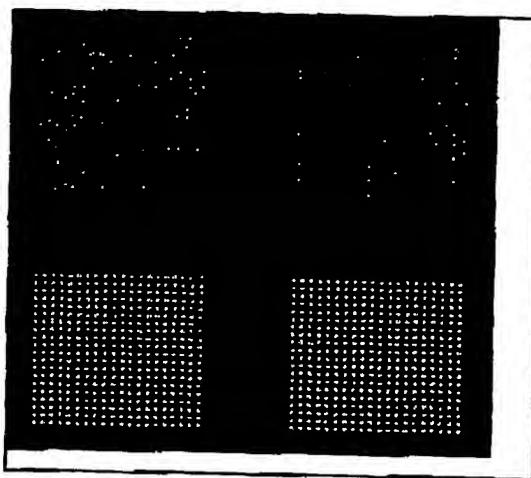
Array 1

10

15

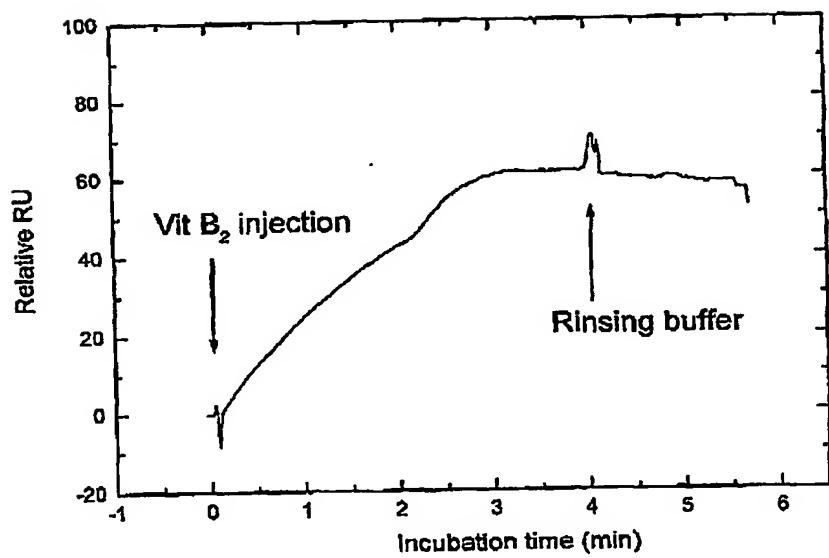
Array 3

20

**Array 2****Array 4**

- 25 -

FIG 4



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